UNDERSTANDING CUSTOMER PRODUCT CHOICES: A CASE STUDY USING THE ANALYTICAL HIERARCHY PROCESS

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The Analytical Hierarchy Process (AHP) was used to characterize the bridge material selection decisions of highway officials across the United States. Understanding product choices by utilizing the AHP allowed us to develop strategies for increasing the use of timber in bridge construction. State Department of Transportation engineers, private consulting engineers, and local highway officials were personally interviewed in Mississippi, Virginia, Washington, and Wisconsin to identify how various factors determine their choice of a bridge material. The Analytical Hierarchy Process was used to quantify this subjective data and to model the selection decision for different groups of decision makers (customers). Prestressed concrete was the material of choice in the majority of cases. This was followed by reinforced concrete, steel, and timber. Local highway officials chose timber more often than did either group of engineers. These results indicate that timbe will remain a niche market for bridge applications.

INTRODUCTION

Understanding how a customer chooses a product may be one of the most important factors in marketing. As wood products become increasingly engineered, competition is no longer just between different species, but between competing materials. New engineered timber now competes directly with steel, plastics, or concrete. This has been demonstrated recently in the United States as timber enters the highway bridge market for rural bridge replacement. A thorough understanding on how highway officials (customers) choose a bridge material will allow strategies to be developed to enhance timber's market share.

The choice of a bridge material is

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the most important decision bridge designers make, and it has long-term consequences for the owner of the structure (Johnson 1990). Bridge material selection is a complex decision, with many individuals involved, and many factors of bridge design, use, and maintenance to be considered. It is not uncommon to have state Department of Transportation (DOT) officials, private consultants, and local officials work together on a bridge replacement decision. Each of these groups may have their own preferences concerning bridge materials. Often a consensus is necessary to determine the best material to use at a given location.

Highway officials and engineers across the United States have been asked tore-evaluate their position on the use of timber as a bridge material. Extensive promotion and training began in 1989 by the Timber Bridge Initiative Program (TBIP 1990) to inform and educate bridge engineers and highway officials concerning the benefits of the modem timber bridge. Since its inception, the TBIP has sponsored the construction of over 300 modem timber bridges in 48 states and assisted in 20 million dollars of research, education, and bridge support activities (USDA 1994). However, the long-term viability of timber bridges will depend not only upon this *technology push,* but also on the competitiveness and acceptance of the concept in the marketplace, the *market pull.* Unfortunately, highway officials across the United States often have negative perceptions of timber as a bridge material. Studies by Clapp (1990) and Luppold (1990) have confirmed that highway officials are not ready to place timber in the same bridge material classification as prestressed concrete, steel or reinforced concrete. Highway officials have stated that timber is short lived, difficult to inspect, expensive, high in maintenance, and low in strength.

Many factors are known to effect the choice of a bridge material. *Physical characteristics or site specific factors* include roadway alignment, length of clear span, clearance above waterway, hydraulic capacity requirements, and required loading capabilities. Yet, there are numerous *non-structural characteristics* of the material such as initial cost, maintenance requirements, and others (Table 1) that also may influence this decision. These are the areas which manufacturers can address in trying to influence the choice of bridge material by design engineers.

Scott and Keiser (1984) state that much of the research that is done in industrial markets to identify and evaluate new opportunities is qualitative and unstructured. We demonstrate in this study that quantitative and structured analysis of decision makers can be a useful tool for understanding customers and their perceptions. We develop a behavioral model of bridge material selection for several states and for several levels of decision makers. Important non-structural factors (criteria) in the bridge material selection process were identified by Smith and Bush (1995). We use the six highest rated factors in the Analytic Hierarchy Process (AHP) to model the bridge material decision. The AHP model helps us analyze how important decision criteria directly influence the overall bridge material decision.

The Analytical Hierarchy Process (AHP)

Although various techniques exist for modelling decision making, the Analytical Hierarchy Process (AHP) was chosen for this study. The AHP can be used as a behavioral, as well as a normative model of decision making. The Analytic Hierarchy Process, developed by Thomas Saaty in the early 1970s, allowed us to quantify and aggregate subjective opinions. Saaty (1980) states that the practice of decision making is concerned with weighting alternatives which fulfill a set of desired objectives. This multicriterion, multiperson model structures the decision process into a hierarchy. Through a set of pairwise comparisons at each level of the hierarchy, a matrix can be developed, where the entities indicate the strength with which one element dominates another with respect to a given criterion.

Harker and Vargas (1987) indicate that there are three principles used in the AHP for problem solving

(1) *decomposition* - structuring the elements of the problem into a hierarchy,

(2) *comparative judgments* - generating a matrix of pair-wise comparisons of all elements in a level with respect to each related element in the level immediately above it where the principal right eigenvector of the matrix provides ratio-scaled priority ratings for the set of elements compared, and

(3) *synthesis of priorities* - calculating the global or composite priority of the elements at the lowest level of the hierarchy (i.e., the alternatives).

The four basic axioms that the AHP is based upon is summarized by Harker (1989) as follows:

Axiom 1. Given any two alternatives (or sub-criteria) i and j out of the set of alternatives A, the decision-maker is able to provide a pairwise comparison a_{ij} of these alternatives under any criterion c from the set of criteria C on a ratio scale which is reciprocal; i.e., $a_{ji} = 1 / a_{ij}$ for all $i, j \varepsilon A$.

Axiom 2. When comparing any two elements $i, j \varepsilon A$, the decision-maker never judges one to be infinitely better than another under any criterion $c \varepsilon C$; i.e., $a_{ij} \neq \infty$ for all $i, j \varepsilon A$.

Axiom 3. One can formulate the decision process as a hierarchy.

Axiom 4. All criteria and alternatives which impact the given decision problem are represented by a hierarchy. That is, all the decision maker's intuition must be represented, or excluded, in terms of criteria and alternatives in the structure and be assigned priorities which are compatible with the intuition.

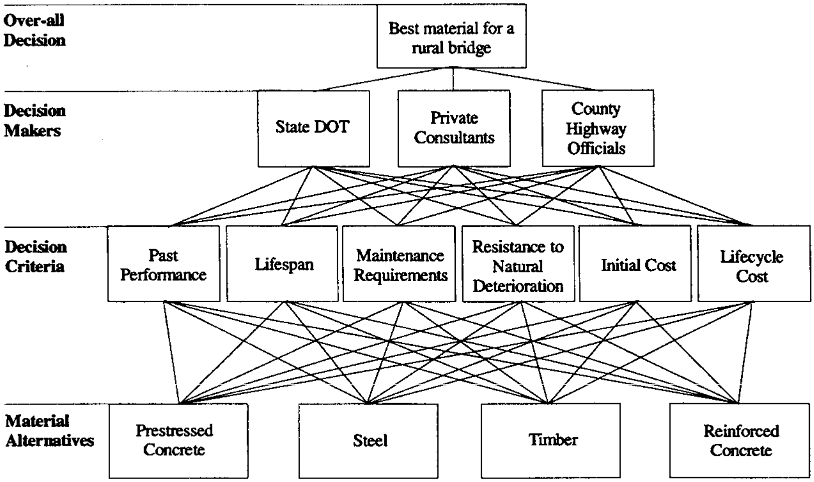
METHODS

Based upon earlier research by the authors (Smith and Bush 1995), six important decision-making criteria were determined for material choice. These six criteria included *lifespan of material, past performance, maintenance requirements, resistance to natural deterioration, initial cost, and lifecycle cost.*

The decision groups for the model were State DOT engineers involved in rural bridge replacement, private consulting engineers, and local highway officials. The four material alternatives for the decision were prestressed concrete, steel, wood, and reinforced concrete. Based upon this information, an AHP decision model was built to evaluate the decision making process in four selected states (Figure 1).

Personal interviews were conducted in four states which included Missis-

FIGURE 1. THE AHP MODEL OF THE BRIDGE DECISION PROCESS.



sippi, Virginia, Washington, and Wisconsin. These states were chosen because of their different resource base, decision making protocol, climatic conditions, geographical locations, and past history with timber bridges. Table 2 summarizes the decision characteristics in each state.

AHP CALCULATION

To demonstrate how the AHP model was developed for each highway official, an example based on county engineers in Wisconsin is provided. In August of 1993 nine county highway commissioners/engineers agreed to participate in completing the paired comparison questionnaire used to develop the AHP decision models. The responses were entered into a personal computer using the program Expert Choice (1992). Individual results were geometrically averaged and one composite matrix was developed (Table 3).

A rating scale from 1 to 9, as recommended by Saaty (1980), was used for the paired comparisons. The number 1 indicating that compared factors were equal in importance and 9 indicating that one factor was extremely more important than another. First, paired comparisons of importance were made between the six selected bridge criteria. Under each criteria, paired comparisons were made for preferences of bridge materials. Again, a rating scale from 1 to 9 was used for preferences of one material over another. Calculation of a final priority vector for bridge material preference proceeds in the following way. First, the data in the bridge criteria matrix are normalized by column. Second, the values in each row are averaged to produce a vector of priorities for each bridge criterion (Table 4). Third, similar calculations are then repeated for each matrix of material preference under a given bridge criterion, e.g. past performance (Tables 5-6). Upon completion of these steps,

FIGURE 2. AHP COMPUTATION OF THE FINAL PREFERENCE VECTOR.

	Bridge Materials Priority Vectors						Bridge Criteria Priority Vectors		Final Preference Vector	
	PP	LS	MN	RS	IC	LC	0.14			
Prestressed Concrete	0.33	0.27	0.42	0.32	0.23	0.28	0.17		0.31	Prestressed Concrete
Steel	0.09	0.16	0.08	0.09	0.15	0.09	0.22	=	0.11	Steel
Timber	0.20	0.23	0.23	0.26	0.32	0.31	0.11		0.26	Timber
Reinforced Concrete	0.38	0.34	0.27	0.33	0.29	0.31	0.19		0.32	Reinforced Concrete
							0.16			

FIGURE 3. DECISION MODEL RESULTS FOR WISCONSIN COUNTY ENGINEERS.

GOAL: Best material for a rural bridge 1.00

Scale: 0 to 1	Pastperf 0.14	Lifespan 0.17	Maintenc 0.22	Resistac 0.11	Intial 0.20	Lifecycl 0.16
Prestressed Concrete	0.33	0.27	0.42	0.32	0.23	0.28
Steel	0.09	0.19	0.08	0.09	0.15	0.09
Timber	0.20	0.23	0.23	0.26	0.32	0.31
Reinforced Concrete	0.38	0.34	0.27	0.33	0.29	0.31

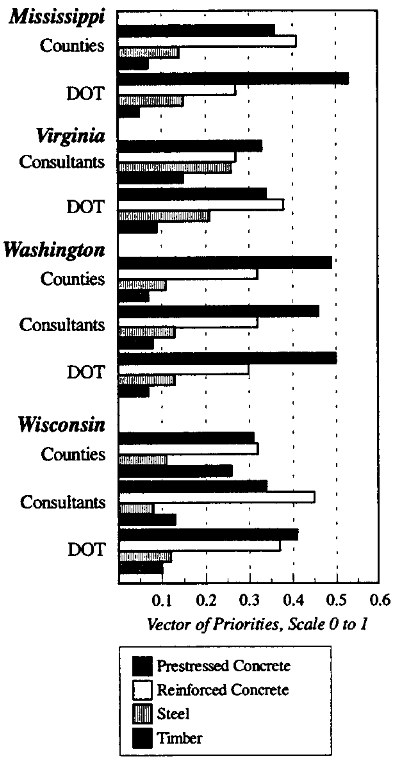
the final composite preference vector for bridge material is the matrix product of (1) the matrix composed of bridge material preference vectors and (2) the vector of bridge criteria (Figure 2). This is the choice of bridge material for the decision maker (in this case, county highway commissioners/engineers in Wisconsin) based upon the criteria measured (Figure 3).

RESULTS

To determine if the four selected states (Mississippi, Virginia, Washington, and Wisconsin) were representative of their respective geographic regions, a Multivariate Analysis of Variance (MANOVA) was calculated for the selected criteria between the individual state and its region. No significant difference ($<$ .05) between each state and its region on these six factors could be shown. Analysis of Variance was used to determine if the states differed from others in the respective regions based on perceptions of timber as a bridge material. Again, no statistical significant differences could be shown. These results indicate that each state is representative of the region in which it is located and should provide a good indicator of bridge decision making in that region. Table 7 summarizes the AHP decision model for each state and decision group. Figure 4 illustrates the product choice by each state and decision group.

Individual decision models can be combined arithmetically to perform statistical analyses (Saaty 1993). To determine if differences existed between states or decision making groups, non-parametric statistical procedures were utilized. Non-parametric procedures are recommended when sample size is small or the distribution of the population from which the data is obtained is uncertain (Hollander & Wolfe 1973). The importance of the six major criteria in the bridge decision were quite uniform across decision making groups and between states (Table 8).

FIGURE 4. CHOICE OF BRIDGE MATERIALS BY STATE AND DECISION LEVEL.



This agrees with earlier findings by the authors (Smith & Bush 1995) that major criteria are similar by groups and regions. Only for the criteria of *maintenance* did significant differences (p = .05) exist between the four states. This is to be expected because maintenance is strongly affected by climatic differences and local procedures.

Among the three major decision groups (DOT, private engineers, and local officials), aggregated across the four states, differences existed in the choices of steel and timber. Among the four states aggregated across the three decision groups only reinforced concrete was not statistically different. In the states of Virginia and Wisconsin differences existed between decision makers' preferences for timber. Both prestressed concrete and reinforced concrete were deemed to have different preferences across decision groups in Mississippi. Only in Washington were the preferences for bridge materials not statistically different by decision group. These results indicate that even though decision criteria are viewed similarly, the extent to which various bridge materials are perceived as meeting those criteria varies between states and between decision making groups.

Sensitivity analysis was run on each model to determine if increasing the perceived performance on one or more criteria would effect the bridge decision. Prestressed and reinforced concrete were rated so much higher than steel and timber, that changes in the criteria seldom resulted in changes in the decision. Only if initial cost become dominant in the decision would private consultants or local officials chose timber over steel. In no situation would Department of Transportation officials select timber based upon the six criteria measured. Department of Transportation engineers favored prestressed concrete.

This may be attributed to their exposure to state and Federal highway bridges and a lack of familiarity with timber design. Private consultants and county officials favored prestressed and reinforced concrete for rural bridges.

In Mississippi, only if *initial cost* became extremely important would county engineers consider using timber instead of steel. No changes would effect the Mississippi DOT engineers' decisions concerning timber. Private consultants in Virginia would choose timber above all other materials if *initial cost* became very important. No changes in criteria importance would affect the decision of DOT engineers in Virginia. In Washington, as *initial cost* becomes more important, local engineers and private consultants would favor timber over steel, but never over concrete. Again, no changes in criteria importance would affect the decision of Washington DOT engineers. Wisconsin highway officials would prefer timber as *initial cost* became very important and DOT engineers would favor timber over steel when *maintenance* became increasingly important. No changes in criteria importance would affect the bridge material decision of private consultants in Wisconsin.

Conclusions and Discussion

Decision making applications of this research indicate that the Analytic Hierarchy process can be utilized in a group situation to understand product choices by customers and to assist highway officials in their choice of a bridge material. This model reflects the current bridge situation in the United States, with prestressed and reinforced concrete being the major bridge material chosen over seventy percent of the time by highway officials.

Decision makers are in good agreement about the criteria that are important in the design decision. Across the United States, these individuals rated the most important criteria similarly by region and decision group. *Maintenance requirements, initial cost, and past performance* were the most influential criteria in choosing a bridge material. However, these criteria, when applied to the AHP decision models, influenced the choice of bridge material differently. Nevertheless, prestressed concrete and reinforced concrete were the materials of choice by every group in each state. These results indicate that *initial cost* may be a competitive advantage for timber in bridge design. However, timber is rated so low based upon the other 5 criteria that it will very seldom be chosen as a rural bridge material. As little can be done with the criteria of *past performance* of a bridge material, educational efforts are needed emphasizing that modem designed timber bridges are not the same as timber bridges built 40 to 50 years ago. Modem prestressed composites of steel and timber have the potential to perform as well, if not better, than other materials.

In addressing the criteria of *maintenance,* modern composites of steel and wood should reduce deflection and movement in timber bridges, which may have caused many of the past problems. *Resistance to natural deterioration* can be improved by building structures with water-shedding joints, good preservative treatments, water proof surfaces, and stressed-type systems where the amount of water movement between wood members is reduced. Realistic comparisons of all bridge materials need to be made based on past design and construction practices. Concrete and steel structures may be performing better, because more of them have been built to modem standards than have timber bridges. *Lifespan and lifecycle cost* will both improve as timber lasts longer and becomes more competitive in the marketplace.

With state DOT engineers controlling the allocation of Federal highway funds, efforts must be made to convince the opinion leaders in this group about the viability of timber as a bridge material. Since this group chose timber the least, every effort is needed to demonstrate that timber is a viable material for rural bridges. To improve timber's perception by engineers, manufacturers need to address timbers' short *lifespan and maintenance requirements.*

Marketing applications of this work indicate that timber manufacturers may need to address criteria other than those measured in this study to increase timber's market share. Other criteria on which timber may compete include *ease of repair, time of traffic interruption, resistance to deicing chemicals, and aesthetics.* Rural roads under county control offer the greatest opportunity for timber use, since these individuals choose timber more often than DOT engineers. Manufacturers may want to look at other areas in which timber may be successful. Railroads, footbridges, light traffic bridges, and scenic covered bridges may offer further opportunities for timber in bridge applications.

This study illustrates how decision modelling can be used to represent product choices by a select group of customers (highway officials). A thorough understanding of the product choice allows marketers to address specific criteria that may influence this decision. In this example only the criteria of *low cost* would allow timber to be considered in some bridge replacement situations. Those promoting timber as a bridge material should consider a niche strategies, trying to meet the needs of their customers in specific locations. The Analytical Hierarchy Process is a good tool for quantifying product choices and can assist market researchers in understanding the customer better.

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APPENDIX

TABLE 1. CRITERIA USED TO EVALUATE BRIDGE MATERIALS.

Government research efforts	Standards specified by AASHTO	Material preference of local officials
Life-cycle cost of material	Past performance of the material in bridges	Availability of design information
Resistance to natural deterioration	Contractor's familiarity with material	Resistance to de-icing chemicals
Expected life of material	Bridge ownership (state, county, town)	Regular inspection requirements
Length of traffic interruption	Designers familiarity with material	Impact on local economy
Maintenance requirements	Industrial promotional efforts	Environmental considerations
Initial cost of material	Aesthetics	Ease of repair
Bridge loading variations	Daily traffic count	

TABLE 2. SUMMARY OF STATE CHARACTERISTICS.

DECISION CHARACTERISTIC	MISSISSIPPI	VIRGINIA	WASHINGTON	WISCONSIN
Geographic Location	South	Mid-Atlantic	Northwest	Midwest
Timber Resource	Southern Yellow Pine/ Hardwoods	Eastern Hard-woods/SYP	Douglas fir	Red pine/ Aspen
Number of Timber Bridges (FHWA, 1992&1993)	3500	63	600	500
Decision Makers	State DOT/ County Engineer	State DOT/ Private Consultant	State DOT/ Private Consult./ County Engineer	State DOT/ Private Consult./ County Engineer
Standardized Bridge Plans	Yes, none for timber	Yes, Timber for only temporary structure	Yes, Timber for only temporary structure	Yes, plans include timber structures
Control of Rural Roads (USDA 1989)	County Engineer	State DOT	County Engineer	County Engineer

TABLE 3. GEOMETRIC MEAN OF PAIRED COMPARISONS OF BRIDGE FACTORS AS RATED BY 9 WISCONSIN HIGHWAY OFFICIALS.

	Pastperf	Lifespan	Maintenc	Resistac	Initial	Lifecycl
Pastperf	1.0	1.10	0.71	1.0	0.53	1.0
Lifespan	0.91	1.0	0.71	1.4	0.83	1.5
Maintenc	1.4	1.4	1.0	1.7	1.3	1.6
Resistac	1.0	0.71	0.59	1.0	0.67	0.40
Initial	1.9	1.2	0.77	1.3	1.0	1.2
Lifecycl	1.0	0.67	0.63	2.5	0.83	1.0
Total	7.21	6.08	4.41	8.90	5.16	6.70
Normalized Matrix of Paired Comparisons for Wisconsin Counties						
Pastperf	0.14	0.18	0.16	0.11	0.10	0.15
Lifespan	0.13	0.16	0.16	0.16	0.16	0.22
Maintenc	0.19	0.23	0.23	0.19	0.25	0.24
Resistac	0.14	0.12	0.13	0.11	0.13	0.06
Initial	0.26	0.20	0.18	0.15	0.19	0.18
Lifecycl	0.14	0.11	0.14	0.28	0.16	0.15

TABLE 4. VECTOR OF PRIORITIES FOR WISCONSIN COUNTIES.

	Total of normalized row	Average of normalized row	Vector of Priorities
Pastperf	0.84	.84/6	0.14
Lifespan	0.99	.99/6	0.17
Maintenc	1.33	1.33/6	0.22
Resistac	0.69	.69/6	0.12
Initial	1.16	1.16/6	0.19
Lifecycl	0.98	.98/6	0.16

TABLE 5. MATRIX OF PAIRED COMPARISONS FOR PREFERENCES OF BRIDGE MATERIALS UNDER THE BRIDGE FACTOR (PAST PERFORMANCE) FOR WISCONSIN COUNTIES.

	Prestressed Concrete	Steel	Timber	Reinforced Concrete
Prestressed Concrete	1.0	4.9	1.4	0.71
Steel	0.20	1.0	0.56	0.24
Timber	0.71	1.8	1.0	0.56
Reinforced Concrete	1.4	4.1	1.8	1.0

TABLE 6. VECTOR OF PRIORITIES FOR BRIDGE MATERIALS UNDER PAST PERFORMANCE FOR WISCONSIN COUNTIES.

	Total of normalized row	Vector of Priorities
Prestressed Concrete	1.29	0.33
Steel	0.35	0.09
Timber	0.80	0.20
Reinforced Concrete	1.55	0.38

TABLE 7. SUMMARY OF AHP MODELS BY STATE AND DECISION MAKING LEVEL.

STATE	Sample Size	Incon Ratio	PRE	STL	TMB	REF	PP	LS	MN	RS	IC	LC
All states in study	*Priority ratings of material and decision criteria*											
State DOT	29	0.01	0.44	0.15	0.07	0.33	0.16	0.17	0.20	0.16	0.13	0.17
Private Engineers	20	0.01	0.38	0.15	0.12	0.34	0.19	0.13	0.22	0.15	0.14	0.17
County Engineers	24	0.01	0.40	0.12	0.12	0.36	0.13	0.17	0.20	0.15	0.18	0.16
Mississippi												
State DOT	5	0.05	0.53	0.15	0.04	0.27	0.12	0.19	0.21	0.16	0.17	0.13
County Engineers	8	0.04	0.37	0.14	0.08	0.41	0.14	0.11	0.17	0.19	0.19	0.12
Virginia												
State DOT	12	0.01	0.33	0.20	0.09	0.37	0.17	0.15	0.27	0.16	0.09	0.16
Private Engineers	7	0.03	0.33	0.26	0.14	0.27	0.24	0.12	0.26	0.11	0.08	0.19
Washington												
State DOT	4	0.03	0.49	0.13	0.07	0.30	0.18	0.15	0.17	0.14	0.16	0.19
Private Engineers	7	0.04	0.47	0.13	0.08	0.33	0.13	0.12	0.23	0.21	0.13	0.18
County Engineers	7	0.05	0.49	0.11	0.07	0.32	0.09	0.16	.21	0.16	0.14	0.23
Wisconsin												
State DOT	8	0.02	0.41	0.12	0.09	0.37	0.18	0.18	0.17	0.18	0.10	0.19
Private Engineers	6	0.02	0.34	0.09	0.13	0.45	0.20	0.17	0.15	0.14	0.22	0.12
County Commis-sioners	9	0.02	0.31	.11	0.26	0.32	0.14	0.17	0.22	0.11	0.20	0.16

Legend

Incon. Ratio	- Inconsistency Ratio	IC	- Initial Cost
LS	- Lifespan	LC	- Lifecycle Cost
MN	- Maintenance Requirements	PP	- Past Performance
PRE	- Prestressed Concrete	REF	- Reinforced Concrete
RS	- Resistance to Natural Deterioration	STL	- Steel
TMB	- Timber		

TABLE 8. STATISTICAL COMPARISONS BETWEEN DECISION MAKING GROUPS AND STATES.

KRUSKAL-WALLIS PAIRED SAMPLE OR ONEWAY ANOVA P-VALUES						
COMPARISON → / CRITERIA ↓	Decision-Groups[1]	States[2]	Decision-Groups within Mississippi	Decision-Groups within Virginia	Decision-Groups within Washington	Decision-Groups within Wisconsin
Past performance	0.09	0.10	0.88	0.08	0.63	0.67
Lifespan	0.09	0.29	0.88	0.44	0.39	0.74
Maintenance	0.59	0.05	0.56	0.86	0.79	0.67
Resistance to natural deterioration	0.68	0.90	1.0	0.61	0.63	0.27
Initial cost	0.60	0.23	1.0	0.93	0.86	0.08
Lifecycle cost	0.56	0.08	0.66	0.55	0.69	0.42
MATERIAL PREFERENCE						
Prestressed concrete	0.86	0.00	0.03	0.80	0.42	0.43
Reinforced concrete	0.88	0.47	0.03	0.18	0.74	0.06
Steel	0.01	0.00	0.24	0.20	0.80	0.08
Timber	0.07	0.00	0.38	0.04	0.92	0.00

1. Comparison between 3 decision maker groups: state DOT, private engineers, and local officials
2. Comparison between 4 states decision makers: Mississippi, Virginia, Washington and Wisconsin.

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